A Study of the Relationship of the Superior Vena Cava to the Bony Landmarks of the Sternum in the Supine Adult: Implications for Magnetic Guidance Systems

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Abstract

This study was a retrospective investigation of computed tomography (CT) images of an Australian adult hospital population. These images were used to evaluate the spatial relationships of the superior vena cava (SVC) to the midsagittal line, the sternal paracoronal plane, and commonly used landmarks of the sternum. Consistent relationships were found between the long axis of the SVC and both the midsagittal line and sternal paracoronal plane. When the sternal paracoronal plane was used as the plane of reference, the angle of Louis was found to approximate the SVC in 99.5% of cases, and the right 2nd intercostal space approximated the SVC in 94% of cases. Constraints on the use of landmarks are discussed with regard to magnetic guidance systems for catheter tracking.

Successful placements of central venous catheters (CVCs) require the skills of highly trained personnel. These procedures are usually carried out by medical specialists, including nurses, doctors, anaesthetists, and radiologists. Radiographs, which reference radiological landmarks, are the current "gold standard" in medical practice for confirming that CVC tips have been placed correctly. Incorrect placements can cause death or serious injury. In 25% or more of blind bedside CVC placements, the first x-ray demonstrates a need to replace or reposition the catheter to achieve an optimal terminal tip position.[1,2] The x-ray procedure often needs to be repeated until correct placement has been confirmed.

Plain film radiographs are the current standard for verification of terminal tip position. Chest x-rays are visual records of correct placements of CVCs. The limitations of x-rays include high inherent costs and procedural time, as well as time delays between placements and confirmation of terminal tip position. In addition, exposure to ionizing radiation poses risks to patients and assisting staff. Fluoroscopy is also used as a tool to guide CVC placements that are performed in radiology departments. To reduce the risks associated with incorrect placements, there is a clear need for a portable system that enables catheters to be guided and for their terminal tip positions to be confirmed safely at bedsides in either hospital or home environments.

Portable magnetic guidance systems, such as CathRite (Micronix Pty Ltd., Parkside, South Australia, Australia), NAVIGATØR MP (Viasys Medsystems, Wheeling, IL), and the Sherlock (Bard Access, Salt Lake City, Utah) have been developed to display real-time movements of catheter tips toward or away from the superior vena cava (SVC) during placements. The assumption underlying the design of these systems is that the relationships between the SVC and bony anatomical landmarks of the chest are known and well understood. Background research on the anatomy of the SVC and its spatial relationship to the anatomical landmarks of the anterior chest wall and sternum is limited. As a consequence, clinical practice has depended on assumptions regarding anatomical relationships that have been derived from radiographic representations of catheter tip positions on chest x-rays, rather than knowledge of the relationships that the SVC has to palpatable surface landmarks of the anterior chest and the factors that govern these relationships in individual patients.

The coronal and midsagittal planes are the key reference planes in studies documenting the location of the SVC within the chest for central line placement. The coronal plane is a plane through the long axis that separates a person's body into anterior and posterior halves, whereas the midsagittal plane is a plane through the long axis in the person's midline, separating the body into its left and right halves. The sternum lies in a plane referred to as the sternal paracoronal plane, which has an oblique relationship to the coronal plane. This term sternal paracoronal plane is used throughout this article when describing the relationship of the sternal bony landmarks to the SVC. We defined this plane by drawing a line of best fit through the sternum in the lateral view. Improved understanding of the spatial relationship of the SVC to the sternal landmarks and sternal planes will assist operators in accurate bedside place-

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ment of CVCs when using magnetic guidance systems. Improvements in the use of magnetic guidance systems will lead to reduction in the need for x-rays.[3,4]

Previous analyses[5,6,7,8] of the anatomy of the soft tissues of the central cardiac region and their relationship to the posterior bony anatomy have been based on information provided by chest x-ray. Because the radiographic borders of the SVC are ill-defined, interpretation of catheter tip positions in chest x-rays are subject to great interobserver variability.[9] Anteroposterior (AP) chest x-rays are subject to distortion due to magnification of the anterior part of the chest, which causes loss of definition in structures such as the heart.[10] Furthermore, it is difficult to identify azygos and mamillary vein catheter tip placements when using AP chest x-rays. Multiple radiographic views enable the interpretation of a catheter track in three dimensions. More accurate identification of terminal tip position is possible when a lateral chest x-ray is also used with an AP[11] than with an AP view alone.

Materials and Methods

This study was a retrospective investigation of archived image data of 200 randomly selected adult patients from 2005 to 2006, that had been referred for pulmonary embolus studies of the chest using high-definition, contrast-enhanced computed tomography (CT) images. Patients commonly presented with a range of conditions, including nonspecific chest pain, suspected deep vein thrombosis, or postoperative complications. Patients with gross chest pathology or with images that were of poor quality were excluded. Patients' ages ranged from 18 to 91 years, with an average of 56 years, of which 110 patients were male and 90 female. Contrast medium was administered on the right side for 142 patients and on the left side for 58 patients. The study was approved by the Human Research Ethics Committee of the Royal Adelaide Hospital, Adelaide, South Australia.

A Toshiba Aquilion16 CT scanner, using Vitrea (Vital Images, Inc., Minnetonka, Minnesota) two-image viewing software, version 3.5, was used to create high-definition images from a full-volume contrast examination of each patient's central cardiovascular system. A Hewlett-Packard workstation with a xw8000 FlexScan L885 screen was used to analyze the data. The accuracy of the system and software that generated this data set was submillimeter, with the limiting factor for the accuracy of measurements being the skills of the investigator to correctly identify the anatomical structures, such as the borders of the SVC, that were used as landmarks. It has been previously reported in the literature that the reliability of CT measurements is high.[16,17]

Patient data sets consisted of CT images that were reconstructed to create three-dimensional color images of patients' bony thoracic structures and venous and cardiac internal volumes. The views included an anterior view in the sternal paracoronal plane and a lateral view of structures that included the SVC in a slice to the right of the midsagittal plane.

Patients' CT slices were used to obtain all measurements, except for those used to evaluate the spatial relationship of the SVC to the bony landmarks of the sternum, for which the reconstructed 3D images were used. The CT imaging system and software allowed for measurements of submillimeter accuracy. The skill of the investigator to correctly identify and mark the appropriate anatomical structures was the main constraint on accuracy of the results.

The following values were measured:

- Distances of sternal landmarks from the sternal notch;
- Lengths of the SVC and approximate distances of the SVC from skin surface and midsagittal line;
- Angulation of the long axis of the SVC relative to the sternal paracoronal plane; and
- The percentage of subjects for whom projections at right angles from sternal landmarks in the sternal paracoronal plane intersected segments of the SVC and adjacent regions.

Measurements were taken from CT slices of structures such as the sternum and contrast-enhanced CT images of the SVC in 100 patients. During selection of the CT slices to be used, the yellow arrows shown in the figures were digitally superimposed onto the CT images to demarcate the junction of the brachiocephalic vein and the SVC (B/SVC) and the junction of the SVC and right atrium (SVC/RA) (ie, the cephalad and caudad boundaries of the SVC). These markers were used as points of reference to measure the length of the SVC. The distance of the SVC to the sternal paracoronal plane (depth from skin surface) and the distance of the SVC to the midsagittal plane were measured from midvessel. These yellow arrows can also be seen on the reconstructed 3D images (eg, Figures 1, 2, and 4), which were used to evaluate the spatial relationships of the SVC to the angle of Louis and other sternal landmarks in these 200 patients. The angle of Louis is the articulation between the manubrium and the body of the sternum and is adjacent to the 2nd rib articulation with the sternum. This is also known as the sternal angle or sternomanubrial joint.

To identify the cephalad and caudad boundaries of the SVC for a left-sided approach, the cephalad boundary was identified as a line drawn across the inferior border of the left brachiocephalic junction of the SVC.[12,13] For a right-sided approach, evidence of contrast medium in the left brachiocephalic vein frequently facilitated identification of the junction between the right and left brachiocephalic veins. This junction was considered to coincide with the B/SVC. When the left brachiocephalic was not visible, the azygos vein and the aortic arch were used to determine the position of the B/SVC. Although the caudad boundary of the SVC was frequently difficult to visualize, a determination of the junction was made by assessing the change in the pattern of blood flow, which is laminar in the SVC and turbulent in the right atrium. The caudate boundary was also delineated by cessation of the tubular morphology characteristic of the SVC.

The Reconstructed Color 3D Images

Lateral View

Figure 1 shows a reconstructed 3D image in a lateral perspective (from the right side of the patient) of the bony structures and the contrast-enhanced blood volumes within the SVC slightly to the right of the midline. These blood volumes accurately represent the internal form and structure of the great vessels of the central venous, arterial system and the chambers of

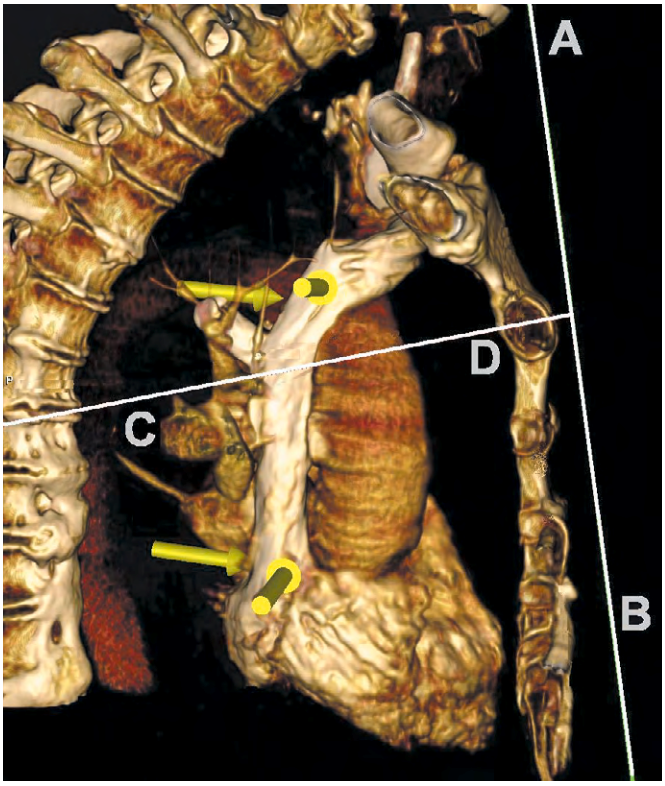

Figure 1. Right lateral perspective (side view), with yellow arrows marking the cephalad and caudad boundaries of the superior vena cava (SVC).

Figure 2. Anterior perspective (frontal view), with yellow arrows marking the cephalad and caudad boundaries of the superior vena cava (SVC). The observer's line of sight is at right angles to the sternal paracoronal plane.

the heart. Soft tissue structures such as the walls of blood vessels are not demonstrated. The ribs have been selectively removed, allowing an uninterrupted view of the region of interest, leaving the SVC, aorta, sternum, and spine visible. The line AB is a line of best fit drawn through the sternum, which is the sternal paracoronal plane. The line CD is drawn at right angles to line AB, intersecting the angle of Louis.

It was observed, although not recorded, that the average thickness of soft tissue over the length of the sternum in the midline was relatively uniform for each subject. Hence the line of best fit (AB), drawn parallel to the sternal paracoronal plane, is also parallel to the skin surface above the sternum. The thickness of this tissue varied from a few millimeters to a few centimeters between subjects.

Anterior View

A reconstructed 3D image of the chest, as viewed at right angles to the sternal paracoronal plane, is shown in Figure 2. The perspective of this view corresponds to that of a posteroanterior (PA) chest x-ray. The arrow that identifies the angle of Louis is seen end-on as a dot. The other two arrows identify the cephalad and caudad boundaries of the SVC. The posterior ribs have been selectively excluded. As in Figure 1, this image shows the bony structures and the internal blood volumes of interest. Note the peripherally inserted central catheter (PICC) in the axillary region of the right subclavian vein. As this is an image of a relatively young patient, no costal cartilage is visible. The internal volumes of the left subclavian, cephalic, and axillary veins are identified by contrast medium. The left subclavian and left brachiocephalic veins are partly obscured by the left clavicle.

Bony Landmarks of the Sternum

An anterior view of a reconstructed image of the sternum, as viewed at right angles to the sternal paracoronal plane, is shown in Figure 3. All other structures have been selectively removed (except for right ribs). The dashed lines represent costal cartilage. The bony landmarks of interest are labeled by arrows. The angle of Louis corresponds to the level of the 2nd rib articulation. The following measurements of the sternum were taken: the length of a line drawn from the middle of the sternal notch to the angle of Louis (manubrial length) and the length of a line drawn from the middle of the sternal notch to the 2nd intercostal space, 3rd rib, and 3rd intercostal space.

The Spatial Relationship Between the SVC and Bony Anatomical Landmarks of the Sternum

Division of the SVC into thirds is common practice for describing the location of terminal tip position. To evaluate the relationship of the SVC to the sternal landmarks, the SVC was divided into three segments. Three boxes, which defined each segment, were superimposed over each of the images. The edges of the boxes were aligned with the cephalad and caudad boundaries of the SVC, as shown in Figure 4. The boundaries of each segment of the SVC were projected at right angles onto the sternal paracoronal plane (line XY). The line ZW passes through the angle of Louis. In this particular case, the projection from the angle of

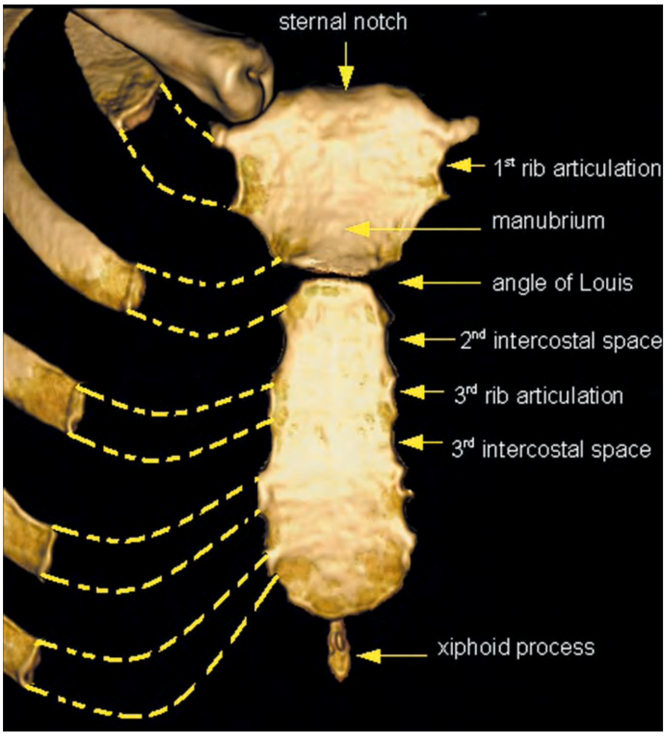

Figure 3. The bony landmarks of the sternum. Measurements were taken from the sternal notch to selected landmarks.

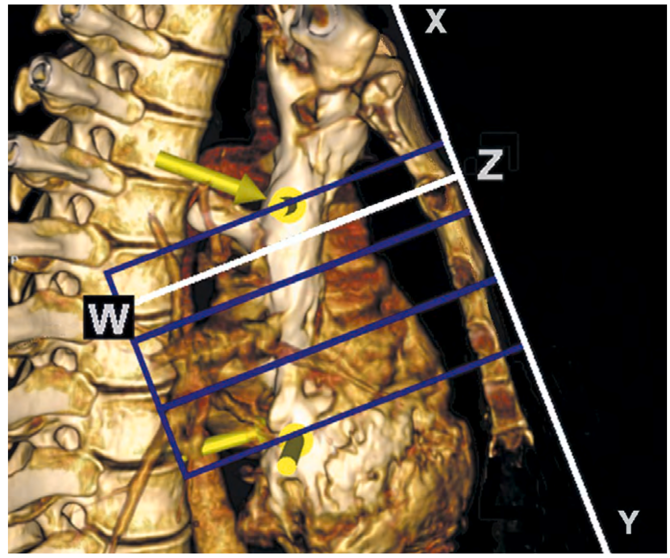

Figure 4. The spatial relationship of the bony landmarks to the superior vena cava (SVC).

Louis, perpendicular to the sternal paracoronal plane, falls in the upper third of the SVC. Each of the 200 patients were analyzed in this way by projecting a line at right angles to the sternal paracoronal plane through the angle of Louis, 2nd intercostal cartilage, 3rd rib, and 3rd intercostal cartilage onto the SVC.

The Paracoronal Plane Angle to the SVC

Using the yellow arrows demarcating the boundaries of the SVC, the distances from midvessel at the cephalad and caudad boundaries of the SVC to the skin surface were measured for 100 patients. These distances, which were used to calculate this angle, were derived from the two-dimensional CT scans taken through the region of the SVC slightly to the right of the mid-sagittal plane.

Figure 5 illustrates the relationship of the long axis of the SVC to the sternal paracoronal plane. The angle created at the intersection of line DE and line FG defined the angle of the SVC to the sternal paracoronal plane. Note that the long axis of the SVC is defined as the straight line drawn between the cephalad and caudad boundaries at the midvessel point.

Visualization of the Azygos Vein

In several images, the azygos vein was clearly visible due to retrograde flow of contrast medium within the great vessels. Figure 6 clearly demonstrates the relationship of the azygos to the SVC, and its posterior branches. The azygos enters at right angles to the SVC, from a posterior direction and is therefore

Table 1.
Measurements of the distances between the sternal notch and angle of Louis (manubrial length), and between the sternal notch and the 2nd intercostal space, 3rd rib, and 3rd intercostal space (n=100).

Measurement	Average(mm) ± SD	Minimum (mm)	Maximum (mm)
Sternal notch to angle of Louis (manubrial length)	51 ± 5	36	67
Sternal notch to 2nd intercostal space	67 ± 7	49	90
Sternal notch to 3rd rib	81 ± 8	57	99
Sternal notch to 3rd intercostal space	94 ± 14	76	119

Table 2.
Measurements of the length of the SVC and distances of the cephalad and caudad boundaries of the SVC from the skin surface and midsagittal line (n=100).

Measurement	Average(mm) ± SD	Minimum (mm)	Maximum (mm)
SVC length	74 ± 12	48	104
SVC depth to skin surface (cephalad)	74 ± 13	48	107
SVC depth to skin surface (caudad)	94 ± 15	65	126
SVC distance midsagittal plane (cephalad)	25 ± 9	8	57
SVC distance midsagittal plane (caudad)	23 ± 11	2	56

difficult, if not impossible, to visualize on plain x-rays except in a lateral view with contrast medium.

Results

Distances of Sternal Landmarks From the Sternal Notch

Table 1 shows the distances from the sternal notch to several sternal landmarks, measured to determine the variation in their relationships to the sternal notch. We found that there was considerable variation between the maximum and minimum values for these parameters: for example a variation of 86% for manubrial length and a range of variation of 74% in the distance between the sternal notch and the 3rd rib. The standard deviation was approximately 10% for each of the landmarks.

Length of the SVC and Relationship Between the SVC and Skin Surface and Midsagittal Line

Table 2 shows the results of length measurements of the SVC, and the relationship of the SVC to the skin surface and the midsagittal plane. Lengths were measured between the cephalad and caudad boundaries of the SVC. The results of these measurements are similar to previously reported data.[5,7] The average length of SVCs was 74 mm, with the maximum length being 104 mm and minimum length being 48 mm.

Measurements of the ventrodorsal distance (depth) between the skin surface and the cephalad boundary of the SVC ranged between 48 mm and 107 mm, with an average of 74 mm. Measurements of the distance between the skin surface and caudad boundary of the SVC ranged between 65 mm and 126 mm, with an average depth of 94 mm. Note that the SVC lies slightly to the right of the midsagittal line.

The average distance of the SVC to the right of the midsagittal plane was 25 mm for the cephalad boundaries and 23 mm for the caudad boundaries. The long axis of the SVC was found to be close to parallel to the midsagittal plane in all subjects; that is, when the cephalad value was low, the caudad value was found to be correspondingly low.

Angular Relationship of the SVC to the Sternal Paracoronal Plane

In Table 3, the average, minimum, and maximum angles between the SVC and sternal paracoronal plane are shown. The average angle between the long axis of the SVC and the sternal paracoronal plane was 26 degrees. Figures 5 and 6 demonstrate features of the SVC that were frequently observed in the study, in that the greatest increase in depth tended to occur in the cephalad third of the SVC and diminished in the middle and lower thirds.

Spatial Relationship of the SVC to Bony Anatomical Landmarks of the Sternum

Table 4 shows that when the sternal paracoronal plane was used as the plane of reference, the angle of Louis (second rib) was found to approximate the SVC in 99.5% of subjects and the second intercostal space in 94%. The 3rd rib approximated the SVC in less than 75% of cases.

When the SVC was divided into thirds, the angle of Louis was found to approximate the lower two thirds of the SVC in

Table 3.
Angles measured between the long axis of the SVC and the sternal paracoronal plane (n=100).

	Average (in degrees) ± SD	Minimum (in degrees)	Maximum (in degrees)
Angle between long axis of SVC & sternal paracoronal plane.	26 ± 5	14	40

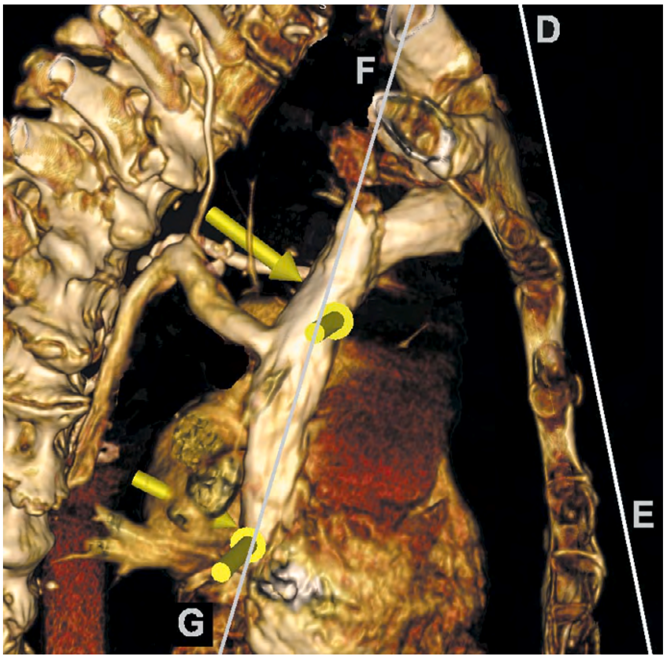

Figure 5. Angle formed between long axis of the superior vena cava (SVC) and the sternal paracoronal plane.

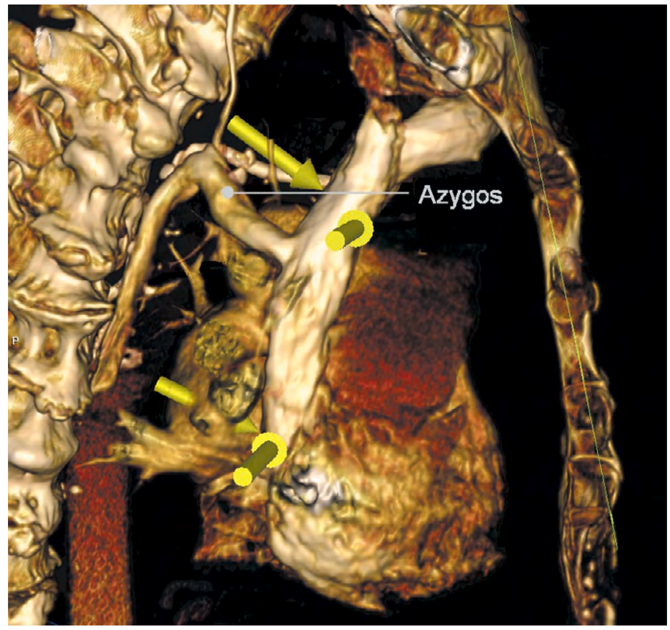

Figure 6. The azygos vein and its entry into the superior vena cava (SVC).

around 50% of patients. The results for the 2nd intercostal space were somewhat more favourable, approximating the lower two thirds of the SVC in close to 85% of patients. A lower value was obtained with projections from the 3rd rib, which intersected the lower two thirds in less than 75% of the patients studied. Table 4 also shows that, in 6% of patients, the 2nd intercostal space projected to the SVC/RA junction, whereas the 3rd rib approximated the SVC/RA junction in 19.7% of patients, with an additional 7% in the RA.

Discussion

There are several factors that influence the relationship between the SVC and the bony landmarks of the sternum. This study of CT images of patients enabled investigation of the length and depth of the SVC in the chest, the relationship of the SVC to the midsagittal plane, and the angle between the SVC and the sternal paracoronal plane. We have introduced the concept of utilizing the sternal paracoronal plane as the plane of reference.

The clinical relevance of the results of this study depends on correlation between the skin surface of the sternum (line AB; Figure 1) and the line of best fit used to define the sternal paracoronal plane. Skin thicknesses were observed to vary between a few millimeters and a few centimeters between subjects but tended to be uniform along the length of the sternum for all subjects. From these observations, we deduced that the skin surface above the sternum is effectively parallel to both the sternum and

Table 4.
Percentage of patients for whom the projections at right angles from sternal paracoronal plane fall into the SVC and adjacent regions. To determine the bony landmark that was in closest proximity to the SVC, the reconstructed three-dimensional images (right lateral perspective) were used (n=200). Abbreviations: B/SVC = Brachiocephalic/SVC junction, SVC/RA = SVC/RA junction, RA = Right Atrium

	B/SVC %	SVC Top 1/3%	SVC Middle 1/3%	SVC Lower 1/3%	SVC/RA %	RA %	Total over SVC%
Angle of Louis (2nd Rib)	0.5	48	39	12.5	0	0	99.5
2nd Intercostal space	0	10	53	31	6	0	94
3rd Rib	0	0.5	32	41	19.5	7	73.5
3rd Intercostal space	0	0	3	48.5	21.5	27	51.5

the sternal paracoronal plane as described, although this may require additional investigation.

The bony landmarks cited, which lie in the sternal paracoronal plane, are often used as references in clinical practice for CVC placements. Clinicians can palpate the sternum and identify its bony landmarks relatively easily. We found that there was considerable variation between patients in the measured distances between the sternal notch and the landmarks investigated. Due to this variation, an understanding of these dimensions is necessary when choosing a sternal landmark as a reference when placing CVC tips.

This study confirms the findings of previous studies[5,7] in that the maximum and minimum lengths of SVCs varied by more than 100% between patients. The lower one third of the SVC may be less than 20 mm in length in some individuals. As a consequence of this variability and relatively small length, although placement of catheters within the SVC can be assured, placement of catheter tips into the lower third cannot be achieved with a high level of confidence. Use of radiology for this purpose is contentious,[7] and the variability of SVC lengths found in this study confirms such a view. Previous studies have shown that there is no correlation between an SVC's length and either cardiac structures[5,7] or other readily measurable patient characteristics such as height, weight, or age.[7]

The results of this study describe the range of distances of the SVC from the midsagittal plane, the range of depths of the SVC beneath the sternum, and the range of variation of the angle between the SVC and sternal paracoronal plane. In this study, we found that the SVC tended to lie parallel to and to the right of the midsagittal plane, which is consistent with normal anatomy. However, cases of persistent left-sided SVCs have been reported[18-20] and, although relatively rare, this possibility needs to be kept in mind when unexpected results are obtained during CVC placements.

Because the angle between the long axis of the SVC and the sternal paracoronal plane was never less than 14 degrees, the results showed that the caudad boundary always tended to be located deeper within the chest than the cephalad boundary. Whereas the long axis of the SVC was represented by a straight line drawn from a midvessel point at the cephalad and caudad boundaries, we noted that, in most cases, the SVC was a concave curve relative to the sternal paracoronal plane. The greatest increase in depth tended to occur in the cephalad one third of the SVC, which can be observed on lateral chest x-rays by the shapes of catheters placed into SVCs.

When viewed in a lateral projection, placement of a catheter into the azygos vein can be readily distinguished from a placement into the SVC.[11] Unintentional azygos placements that have not been recognized as such due to the limitations of single frontal-view x-rays have been reported in at least 1% of all CVC placements.[14,15] As a consequence, multiple views have been recommended when radiography is used for verification of catheter tip placements.[11] Observations of 3D images in which azygos veins were clearly visible in this study (see Figure 6) confirmed this view.

Evaluation of the relationship between the bony anatomical landmarks of the sternum and the SVC revealed a number of strong correlations. When the sternal paracoronal plane was used as the plane of reference, the angle of Louis approximated a point within the length of the SVC in 99.5% of all subjects. The 2nd intercostal space was found to approximate the SVC in 94% of subjects, with diminishing correlations among both the 3rd rib and 3rd intercostal space and the SVC. As well as evaluating the relationship of sternal landmarks to the SVC along its entirety, the proximity of particular landmarks to segments (thirds) of the SVC was also evaluated. The 2nd space was found to approximate the lower two thirds of the SVC in 84% of subjects.

There are a number of implications of these findings for magnetic guidance systems. Because of the range of variability in each of the values presented in the data above, a lateral projection as well as a frontal view are required to provide clinicians with information that is adequate for reliable terminal tip position. In addition, the more distal a chosen landmark is from the angle of Louis, the more likely it is that the landmark will approximate the SVC/RA junction or RA. This finding is significant when bony anatomical landmarks of the sternum are used to aid the placement of catheter tips to a particular portion of the SVC.

Conclusion

The sternal paracoronal plane is a convenient plane of reference that can be used to determine the region of the chest that is most likely to be associated with the SVC. Certain bony anatomical landmarks of the sternum can be used with a high level of confidence as references for guiding CVCs to the SVC. The sternal paracoronal and midsagittal planes have a predictable relationship to the SVC. For example, the normal projection from the sternal paracoronal plane through the angle of Louis intersected the SVC in 99.5% of subjects in this 200 patient study.

Magnetic tracking systems, which are gaining acceptance for the placement of CVCs at the bedside, require an understanding of the spatial relationship between the SVC and the bony anatomical landmarks of the sternum. This study, using 3D images, demonstrates that, for safe guidance of catheters within the venous and cardiac systems, 3D representations of terminal tip positions are needed when confirming placements.

In this study, we investigated the anatomical variations that have an impact on central venous catheter tip placement in the SVC and hope that the results contribute to the limited published data on this topic.

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